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TECHNICAL NOTE

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THE STRUCTURE OF THE EXPLORER X MAGNETOMETER SPACE PROBE

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SUMMARY

The Explorer X was designed primarily to house the scientific equipment and allied electronics for a rubidium vapor magnetometer experiment in interplanetary space. A plasma probe for investigating low energy positive particles constituted the secondary experimental equipment in the payload. Power for approximately sixty hours of flight was provided by 35 pounds of silver-zinc batteries. The structure provided spin stabilization and was compatible with the low drag fairing of the Delta vehicle. Thermal control for the payload was maintained by a vaporized coating of aluminum on the exterior surfaces, coupled with a pattern of dull aluminum paint. All materials used in the structure were nonmagnetic; and the use of the lightest materials possible resulted in a total payload weight of 79 pounds.

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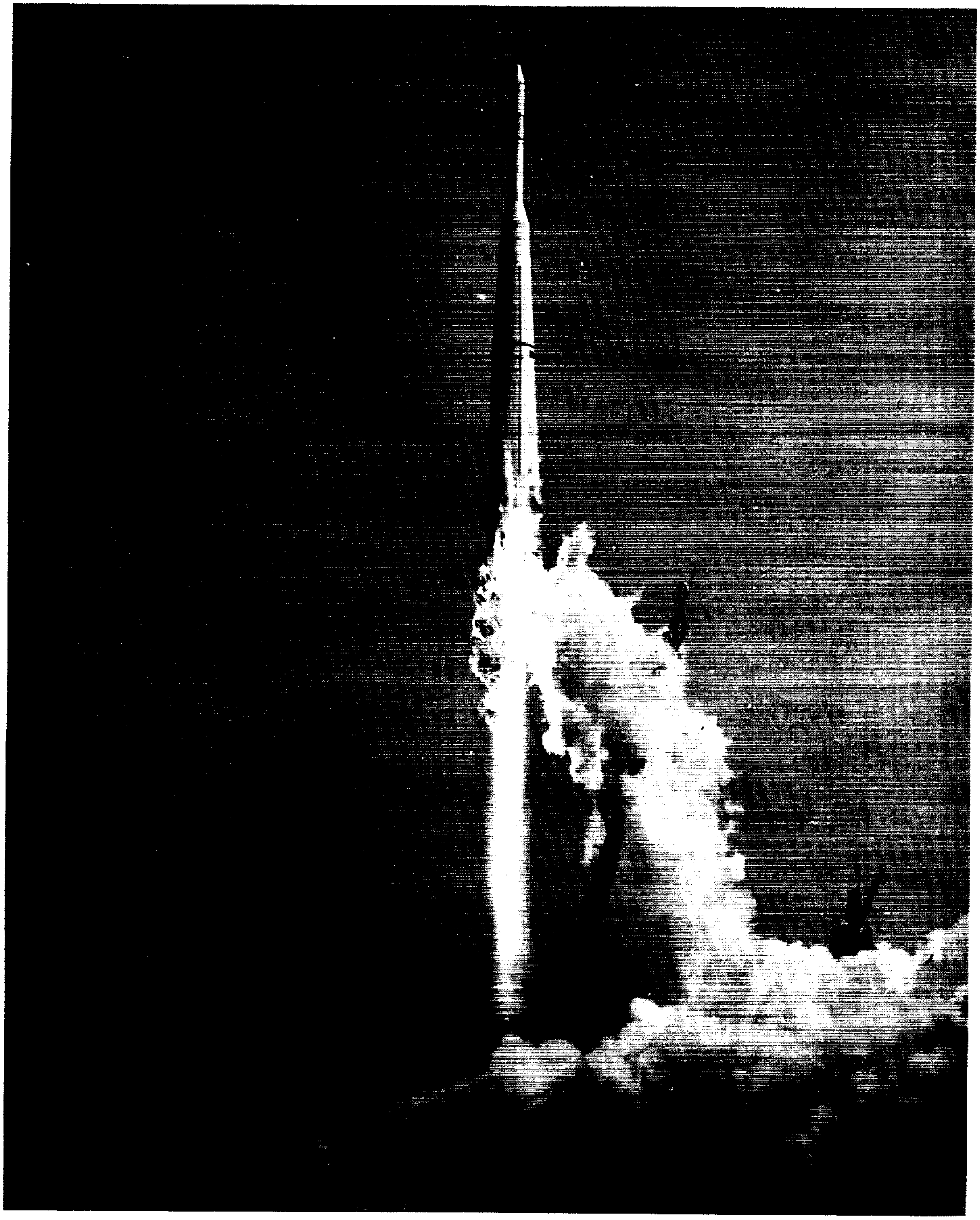

The launching of Explorer X

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INTRODUCTION

The preliminary design of the structure for Explorer X was based primarily on the following four requirements: (1) the magnetometer was to be housed in a magnetically clean environment as far from electronic circuitry as possible, (2) the weight of the structure was to be held to an absolute minimum, (3) 35 pounds of silver-zinc batteries were to be housed in a pressure tight container, (4) the structure was to be compatible with the volume and environmental characteristics imposed by a Delta vehicle with low drag fairing. A fifth requirement, that of maintaining spin stability, was imposed late in the design phase and produced a marked change in the preliminary structure.

In addition to four rigid antennas, the requirement existed for two flux gate sensors to be located as far from the electronic circuitry as possible on a specified angle in a specified plane. Finally, a method of creating a precise bias field about the magnetometer had to be devised.

All structural requirements were met by the configuration shown in Figure 1. The major components are shown in Figure 2. A summary of all the components and their weights is given in Appendix A.

DESIGN

Because of the requirements for nonmagnetic materials and the strict weight limit, magnesium was selected as the structural material. A special run of large, sonically inspected ZK-60 billets was ordered for this purpose. A filament-wound fiberglass structure was designed to support the magnetometer. Aluminum foil 0.001 inch thick was wound between the layers of fiberglass to create a Faraday shield.

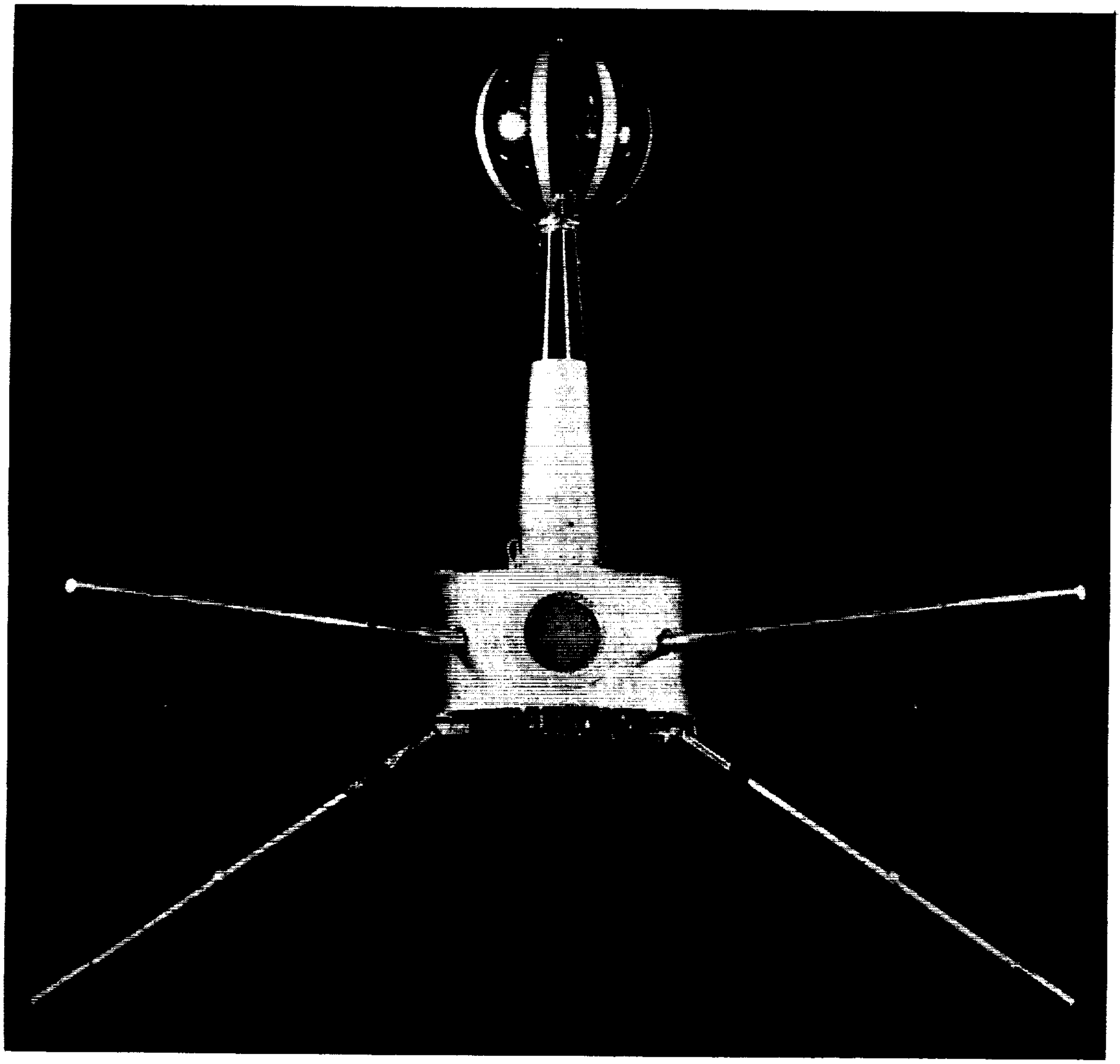

Figure 1 - Explorer X assembly

Since there was no initial requirement for spin stability, the relatively heavy battery pack was located in a sealed cylindrical housing at the center of the payload and was surrounded by the relatively light electronic circuitry (Figure 3). The primary reason for this arrangement was to minimize structural weight and simplify the sealing problems. Since all of the batteries were assembled into a single pack, all wires could be lead through a single connector. The connector was located in the side rather than the top of the battery housing. This arrangement permitted easy access to the batteries during preliminary payload testing since the battery pack could be plugged into the electronics while the sealing cover was off.

The battery connector itself was not sealed but was simply secured in a hole through the side of the housing. The sealing of the connector was accomplished by the mating cable harness on the outside of the hole through the housing. The housing cover could be quickly installed by the use of two screws and a marmon clamp. The end result of this design was an easy method for replacing battery packs without entering the electronics area and by disturbing only one O-ring seal. Simple battery replacement was a definite design goal since many packs were used during the development phases.

Most of the electronic components were mounted on two shelves which were secured around the outside of the battery housing. Each shelf was split radially into two halves and assembled into a wide, shallow groove around the outside of the housing. This method of assembly eliminated the risky procedure of running mounting screws into the

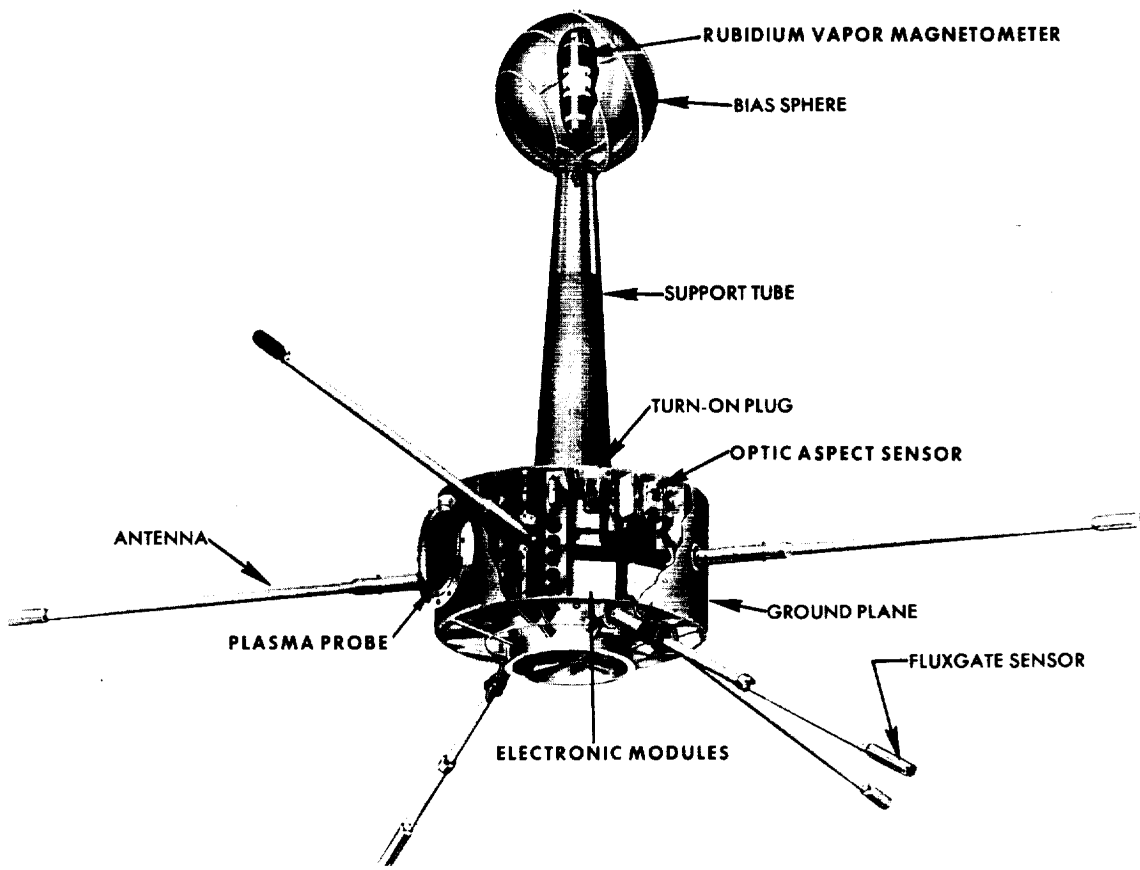

Figure 2 - Cutaway drawing of general assembly

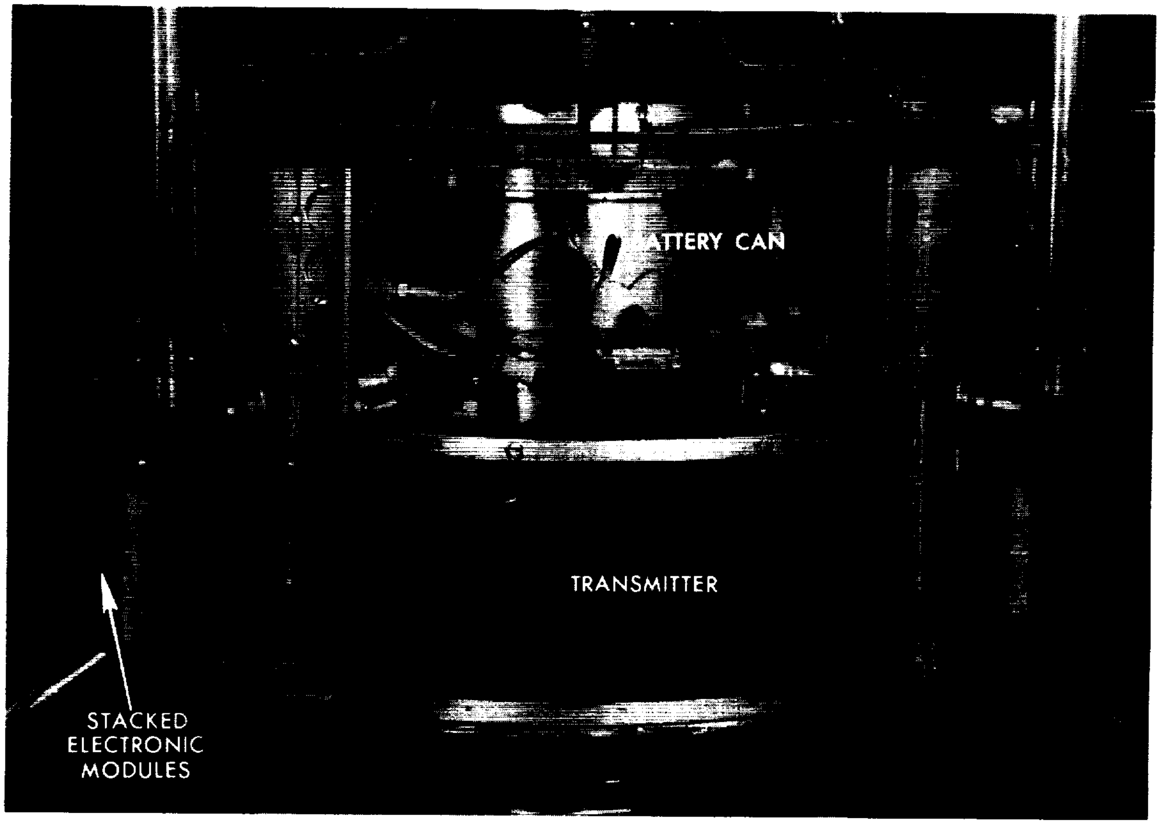

Figure 3 — View of transmitter and other electronic modules

thin wall of the sealed housing. It also eliminated shear loadings in assembly screws. The two shelves were designed to absorb the substantial impact loads imparted by the antennas which unfolded during second stage acceleration. The loads were transferred from the antenna base to the shelves by a light structure welded together from 0.062 inch magnesium (AZ31B) sheet. The dynamic loads from the entire payload were transferred to the vehicle attach fitting at the base of the battery housing by a pattern of radial ribs.

When the mission of the payload was changed from lunar to interplanetary, the requirement for spin stability was imposed. Several schemes for increasing stability by moving the heavy batteries away from the thrust axis to the periphery of the payload were considered. The possible use of a pressure tight annulus and a family of individual battery cans was also investigated. However, the radical effect which any such stability schemes would have on components and cable harnesses already completed was considered incompatible with the time schedule. As will be described presently, the antennas were redesigned to provide the required spin stability.

The electronics were arranged on printed circuit cards. In order to avoid paying the weight penalty of a rigid structure for securing the ten different circuit cards, each card was potted in plastic foam (Eccofoam FP, with a density of approximately 9 pounds per cubic foot), molded with interlocking feet, and then stacked as shown in Figure 4. Two rods passed down through each stack to secure them.

Every effort was made to avoid the use of electromechanical devices on the payload whenever a more direct and reliable method of performing a function could be used. For example, the use of a complex squib-actuated mechanical release for the antennas and sensor arms was avoided by modifying the nose fairing to permit the arms to bear upon it and extend when it was ejected. Thus, critical payload weight was saved in favor of much less critical first stage weight.

Another example involved the requirement for de-spinning the payload from the normal Delta spin rate of approximately 180 rpm to the more desirable rate of 70 to 100 rpm. De-spin mechanisms frequently are awkward to integrate into structures and are difficult to test under realistic conditions. Therefore, the Douglas Aircraft Company was requested to investigate the possibility of reducing the spin rate of the Delta vehicle to 95 rpm as required for the payload. It was determined that this could be done, since

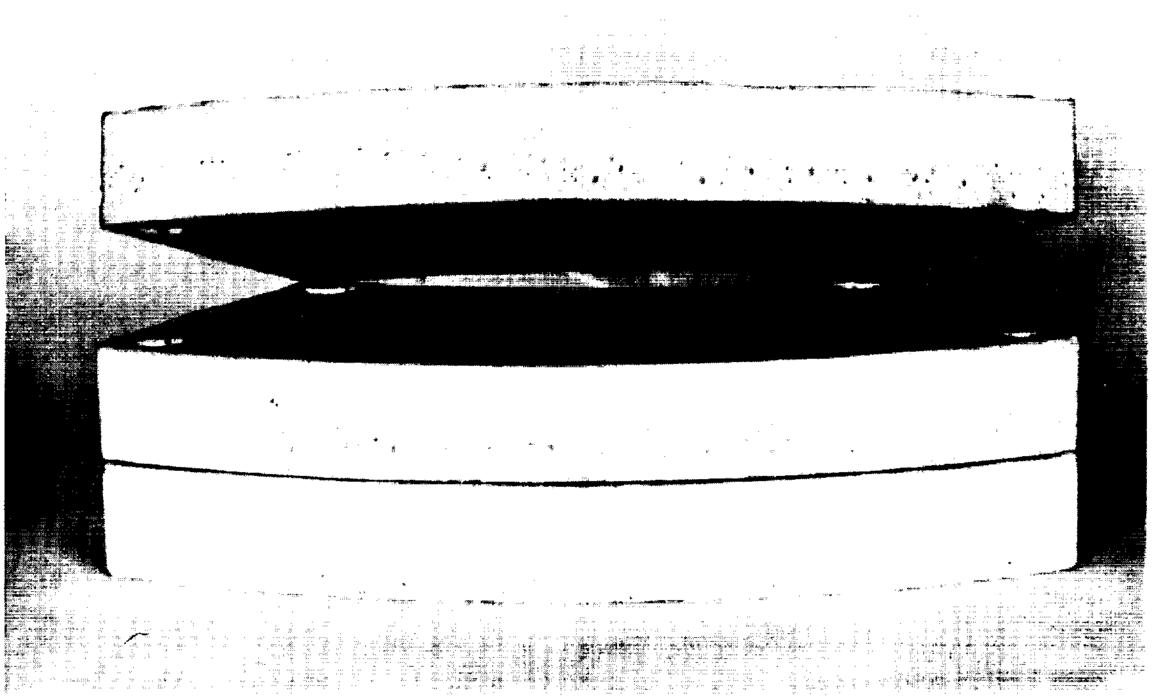

Figure 4 - Stacked dummy electronic modules showing interlocking feet

the third stage trajectory for Explorer X was less critical than on previous Delta orbital missions. Thus, a simple change to the vehicle's retro-rockets eliminated the need for a payload de-spin system.

It is believed that this philosophy of making minor modifications to the standard launching vehicle in order to accomplish major payload mechanical objectives has resulted in a payload of optimum weight and simplicity. Moreover, extremely high reliability was assured because all mechanical functioning parts could be completely and repeatedly tested.

A major component of the transmitter was a potted card which contained two vacuum tubes mounted adjacent to a transistor circuit. Tests showed that anticipated flight vibrations would destroy the filaments within the tubes. Thus, the use of a vibration damping material was mandatory. However, it was also demonstrated that heat carried along the card from the tubes could damage the transistors; hence the provision of an efficient heat sink was also mandatory. The dual requirements of vibration insulation and good thermal conductivity are not normally satisfied in the same material. Theoretical calculations showed that the mass of material required to conduct the heat from 6 watts of power to a sink could not, within existing space and weight restrictions, be formed into an effective vibration mount. Several "steel wool" types of pads, of varying materials and densities, were tried and rejected. Attempts at thermally insulating the transistors from the vacuum tubes were unsuccessful since the 50-hour flight time was long enough to allow the heat to saturate everything on the card. A solution to the problem was found by developing a sponge rubber pad through which braided copper sheaths were inserted (Figure 5). The pad was installed between the card and a major structural heat sink. The ends of the sheaths were flared so that they covered both sides of the pad but remained quite flexible. By determining proper relationships between the quantity of sheaths, the rubber thickness, and the amount of compression, the transmitter was satisfactorily protected.

The antennas originally intended for use with Explorer X were of the same folding, lightweight design as those developed for the Vanguard satellites. However, when the requirement for spin stabilization was imposed, it was decided to increase the moment of inertia about the spin axis by adding one pound of lead to the tip of each antenna. The value of the resulting spin-to-tumble moment ratio was calculated to be 1.03 instead of the previous value of 0.56. As Figure 6 will show, the structure required to support the antenna with the stabilizing weight was considerable; but the total weight increase of approximately 10 pounds was considered acceptable because of the change in missions.

Built into the base of each antenna was a housing for the electronic balancing circuit. A spring loaded piston device, devised to operate within the antenna base, extended and

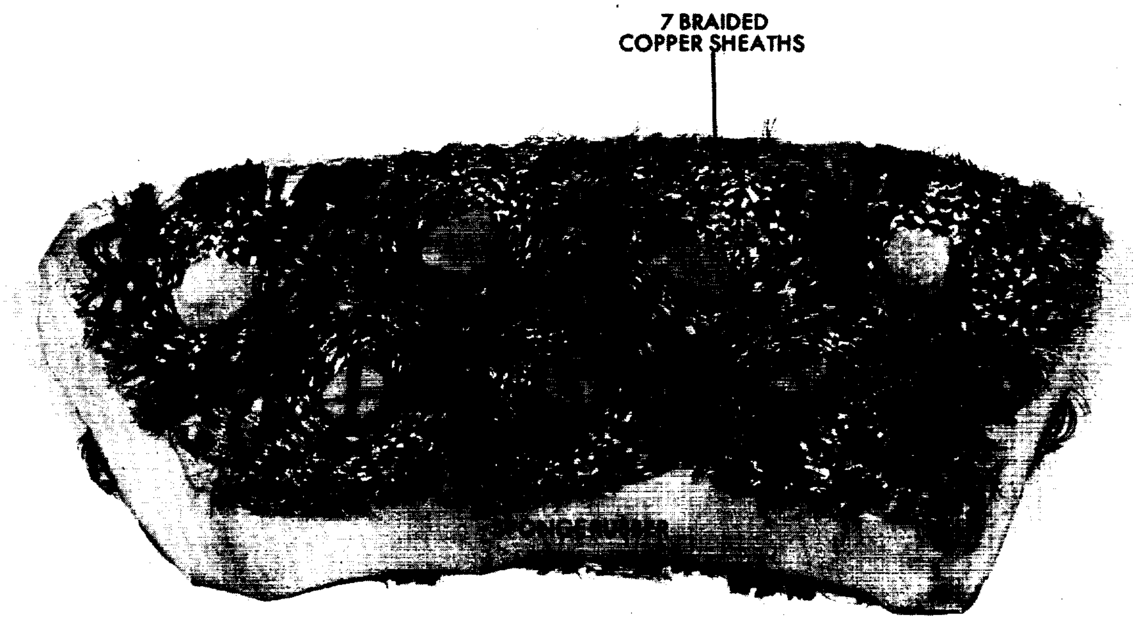

Figure 5 — Combination heat dissipator and vibration mitigator for transmitter

locked the folded antennas (Figure 7). A similar device was used to extend and lock the flux gate sensor arms.

The battery pack used to power Explorer X consisted of the Yardney Silvercells listed in Table 1. The total volume of the batteries, plus insulating spacers, was

Table 1

Yardney Silvercells used in the Battery Pack of Explorer X

Designation	Number Used
PM-05	3
PM-1	8
PM-2	52
PM-3	87
PM-5	16
PM-58	2

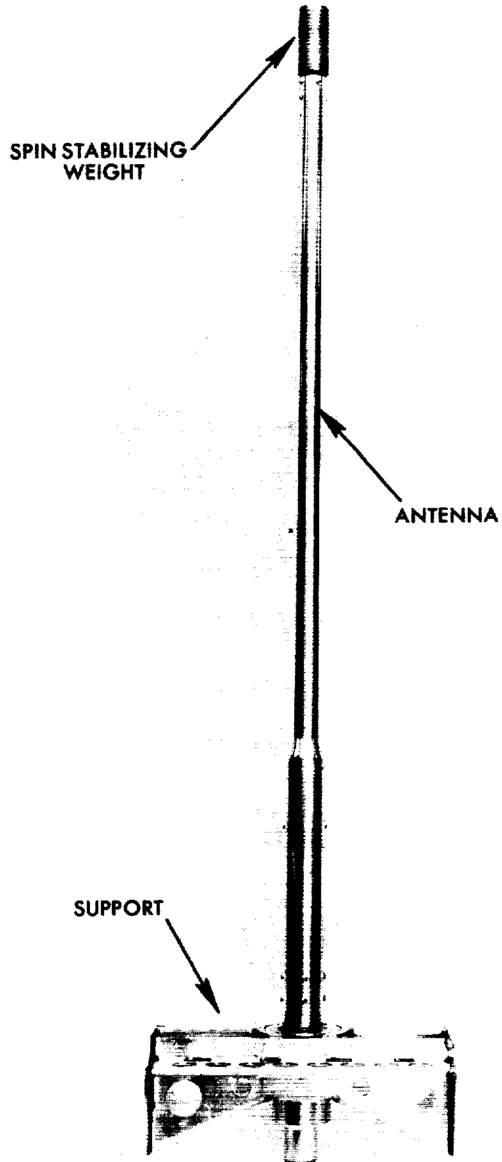

Figure 6 — Spin stabilizing weight on antenna assembly

approximately 500 cubic inches. The volume of the pressure-tight housing was 1051 cubic inches. Since the batteries were held in place by 471 cubic inches of foaming plastic, the available empty space into which the batteries could outgas was only 80 cubic inches. This is a volume ratio of void-to-batteries of only 0.161; the need for some type of a bellows operated pressure relief valve was anticipated. However, as will be described in a later section of this report, it was demonstrated that the foaming plastic would soak up the gas and a relief valve was not necessary.

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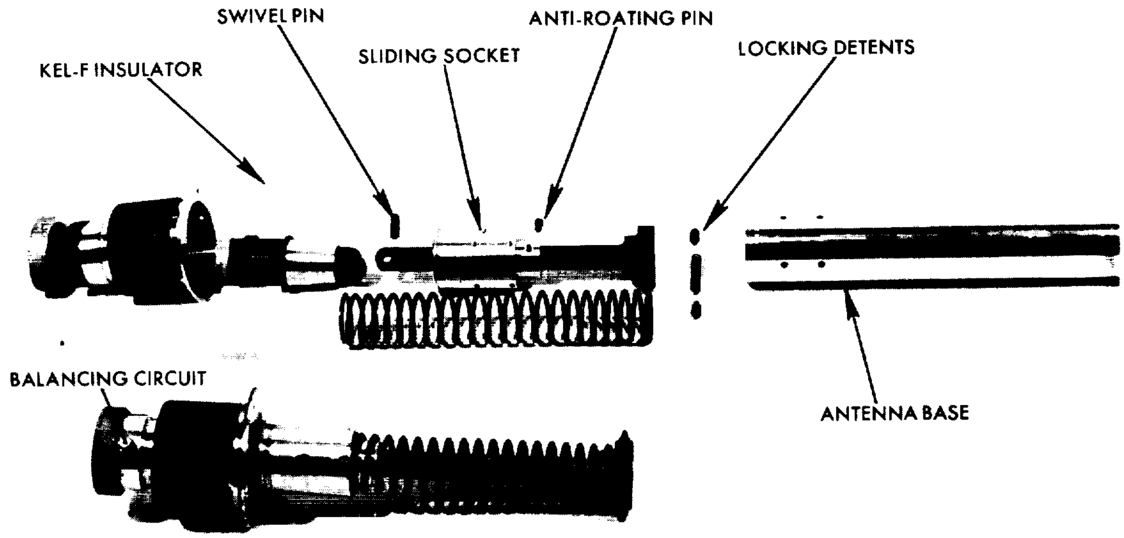

Figure 7 — Antenna folding and locking device

In order to maintain the optimum operating temperature (0° to 40°C) of the payload in flight, a system of surface coatings was developed. A mirror finish was applied to a specific proportion of the surface area by vaporizing a coating of aluminum onto both metal and fiberglass parts. Another portion of the surface area was covered with a dull aluminum paint. Certain exterior surfaces, such as the bias sphere, were coated with a carefully defined pattern of both bright vaporized and dull painted areas. For ease of handling, all treated surfaces were covered with a layer of durable stripable plastic (Spraylat SC-1071 B) which was removed just prior to flight.

FABRICATION

A total of six payload structures were fabricated. The first was a wooden mock-up which proved very useful in coordinating the preliminary efforts of the scientific and structural groups. The second was an electronic engineering model, accurate in every dimension but fabricated largely from easily obtainable aluminum in lieu of magnesium. This model was used to determine the placement of all electronics. The third structure, an accurate assembly of all structural members, was fitted with dummy electronic components of proper weight and center of gravity and subjected to a complete structural design evaluation. The fourth assembly was considered a prototype payload and was the first in which all final designs of the experiments, electronics, and structure were brought together. Final thermal coating systems were developed on this assembly. The fifth and sixth structures became flight models one and two respectively. Since sufficient time was available, the fourth structure (or prototype) was completely reworked upon completion of its test program and became flight model three.

In addition to the payload structures themselves, various items of handling equipment were built, such as a gantry hoisting rig and shipping containers. The need also arose for a device to rotate the assembled payload about an axis which passed through the center of the bias sphere and was parallel to the separation plane. This device was needed for calibrating the magnetometer at various attitudes within a magnetic field coil system located at the Fredericksburg Magnetic Field Station, Corbin, Virginia. Since the sphere axis was approximately 45 inches above the payload attach fitting and 37 inches above the payload center of gravity, the resulting support structure was quite large (Figure 8). A thick walled aluminum can (not shown in Figure 8) was placed around the magnetometer to keep out stray 60-cycle electrical fields.

Six contractors and three government facilities contributed to the fabrication phase of the Explorer X. Special ZK-60 magnesium billets were procured from the Wyman-Gordon Company and the Dow Chemical Company. The unique deep hole boring facilities of the Naval Weapons Plant were used to fabricate the antennas, and their optical equipment was used for applying all vaporized thermal coatings. All plastic parts (excluding fiberglass) were fabricated by the Naval Research Laboratory, and their pattern shop fabricated the wooden mock-up. The magnesium weldments for the antenna supports were made at the Brooks-Perkins Company. The filament wound fiberglass support tubes were made by Lamtex Industries using a 45° helix wind and a CL series resin. Both the Young Development Laboratories and Lamtex Industries furnished the fiberglass spheres. Almost the entire quantity of required metallic structural components was supplied through Washington Technological Associates.

It should be noted that regular commercial ZK-60 magnesium bar stock is not always magnetically clean. Although magnetic fields of less than one gamma might be expected from ZK-60 stock, it was possible to permeate some raw bar stock to over 2000 gammas. Thus, magnetic inspection of raw material prior to any machining was necessary. A system of sonically cleaning, magnetically inspecting, and marking all finished machined parts prior to acceptance was initiated.

TESTING

As soon as the engineering model became available, launch vehicle compatibility tests were initiated. The model was taken to the Douglas Aircraft Company's facility at Tulsa, Oklahoma, where it was installed on an inert third stage. The actual flight fairing was assembled around the payload. Then, the fairing was manually separated and the

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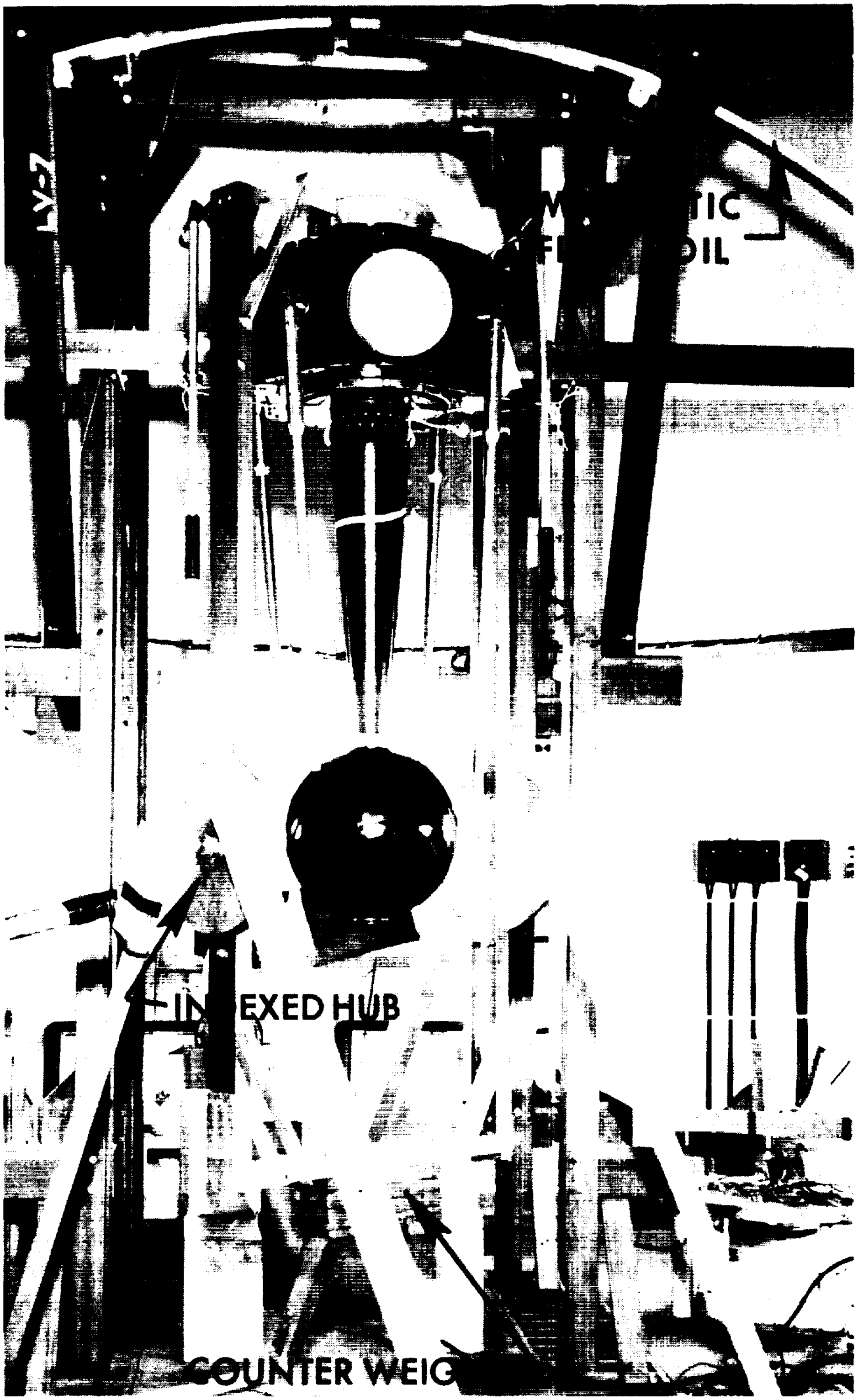

Figure 8 — Fixture for rotating payload about center of magnetic coil system

payload arms were allowed to ride along the inside of the moving fairing halves. It was anticipated that the arms would strike various structural ribs within the fairing while sliding along the inner surface. All points of interference were determined and a series of guide ramps were developed. Also, at this time, the optimum locations of the fairing access holes were determined.

When modifications to the flight fairing had been completed, the payload was again installed within the fairing. Two live ejection tests were performed in the vacuum chamber (Figure 9) at a simulated altitude of 120,000 feet using live explosive bolts and the two 120-pound fairing separation springs. In addition to complete camera coverage, the guide ramps were chalked so that the paths of the unfolding payload arms could be traced. Upon successful completion of these tests, another test was set up (Figure 10) in the vacuum chamber to evaluate the ability of the extended antennas and sensor arms to resist the forces imposed by the firing of the retro-rockets on the launch vehicle's spin table. During the actual launch, three 0.6KS40-HA rockets are fired simultaneously to spin up the second stage. However, during the testing four such rockets were fired simultaneously to evaluate the payload structure. The assembly accelerated from 0 to 146 rpm in 0.6 second but produced no damage to the structure.

Battery outgassing tests commenced as soon as the first battery pack became available. Very little information was available on the rate of outgassing of the subject cells, and that which could be located was applicable only to specific duty cycles, temperatures, current drains, and volume ratios. In order to determine what the pressure build-up of the battery pack would be during flight, the prototype payload was operated under flight thermal-vacuum conditions. After 50 hours of operation at an ambient temperature of 40°C in the vacuum chamber, the housing pressure rose from 6 psi gage to 38 psi absolute, indicating an increase of 17 psi due to outgassing. This increase was acceptable since the structure was tested to 45 psig, but it was decided to reduce the final pressure if possible. During initial leak tests of the battery housing, it was observed that the 6 psig of helium which was introduced into the housing quickly fell to 0 psig, although an electronic leak detector could sense no leak. The battery housing had to be pressurized several times before a steady 6 psig could be maintained; obviously, a considerable volume of helium was absorbed by the foamed plastic. This sponge-like quality of the plastic was utilized during the next outgassing test. After pressurizing the housing to 20 psig for leak checks, the assembly was vented back to 0 psig. (If the pressure valve were quickly closed again, the pressure could be observed to rise slowly to 15 psig as a result solely of the release of helium trapped in the rigid foaming plastic). At the end of that thermal-vacuum test, the pressure rose to approximately 20 psi absolute, an increase of only 5 psi. Thus, the foam could be considered a void, rather than a solid, into which the batteries could outgas. The anticipated need for a bellows operated pressure relief valve was therefore eliminated.

The environmental test program was conducted in accordance with the procedure established by the Environmental Test Committee as stated in the document "Test

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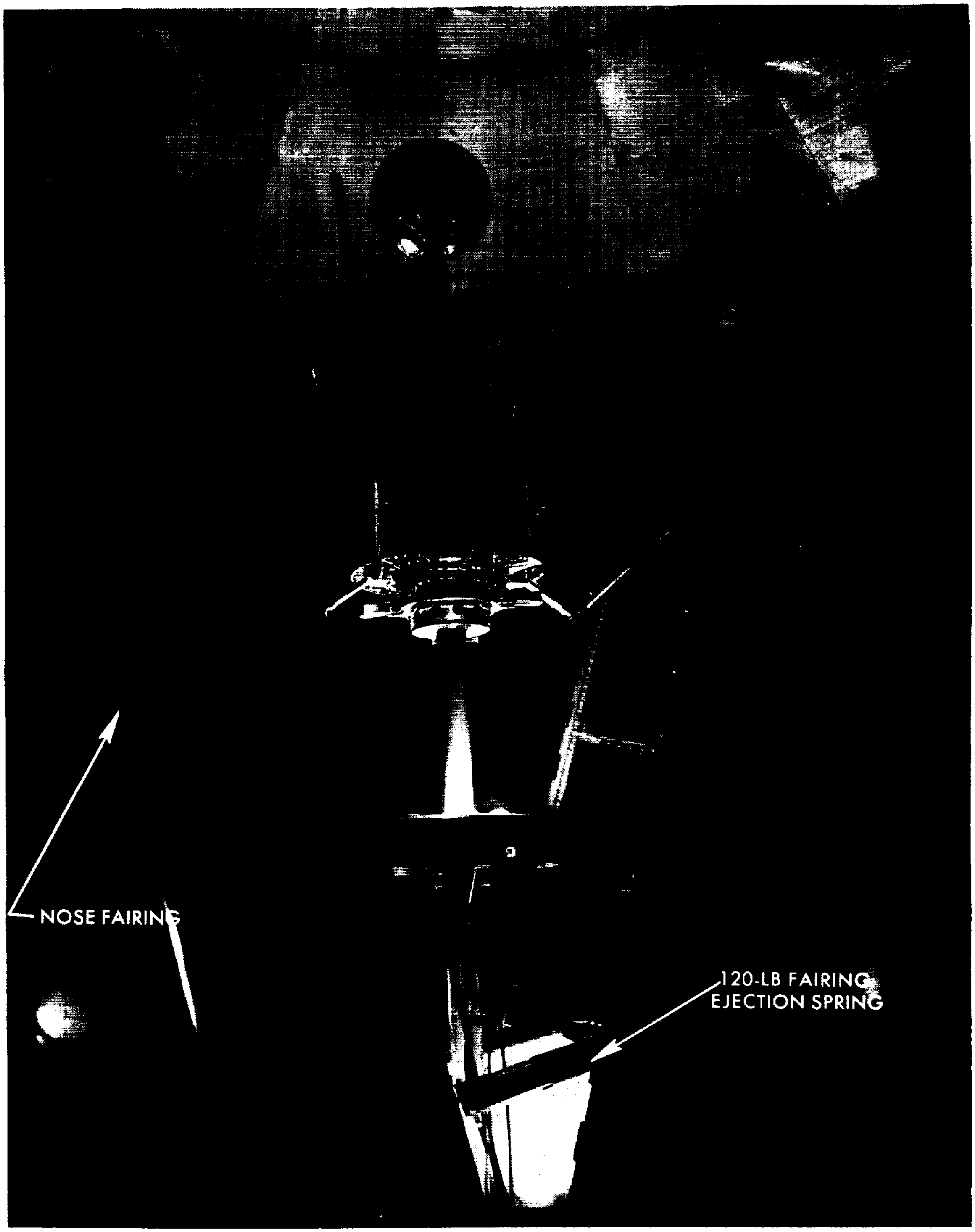

Figure 9 — Nose fairing separation test

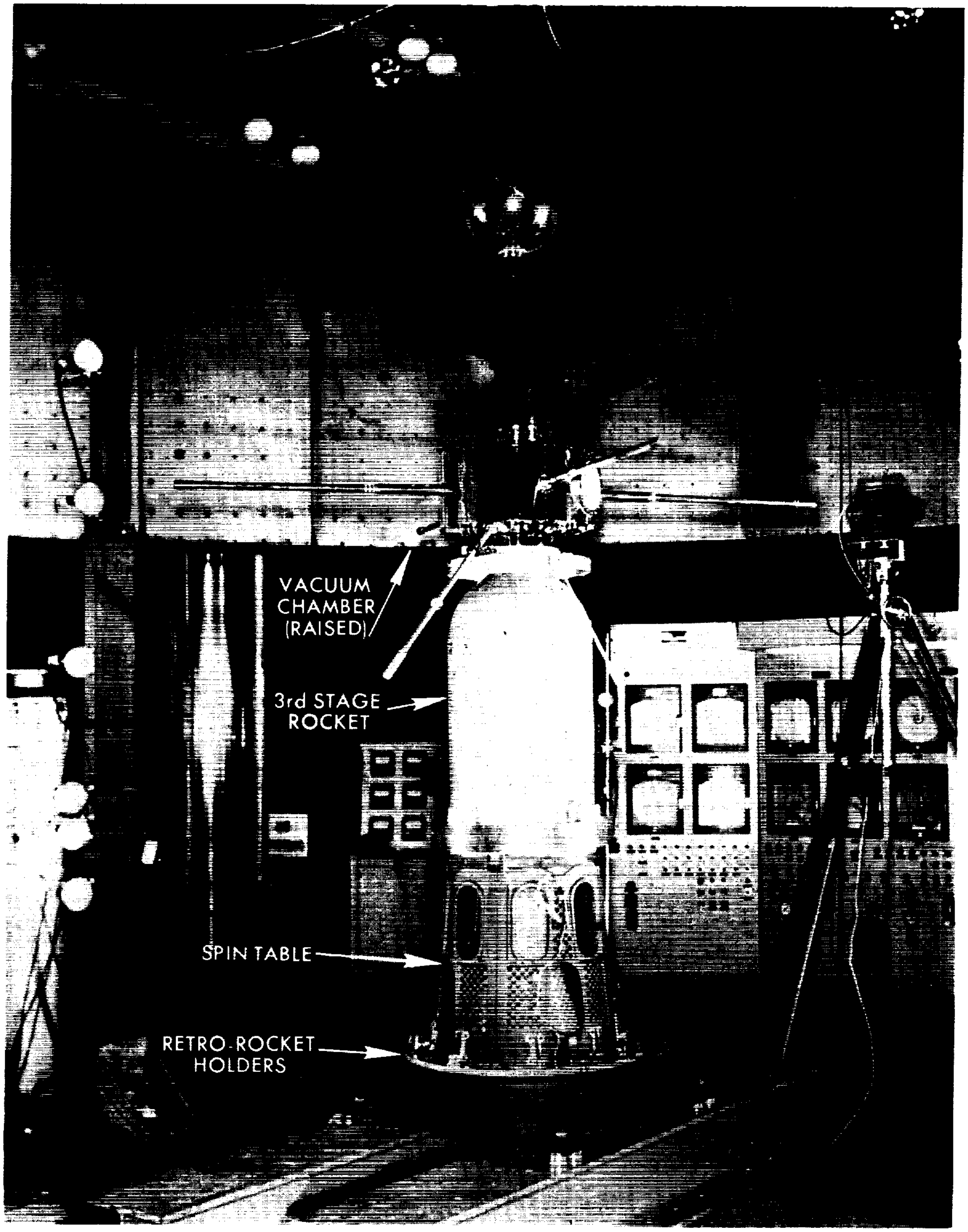

Figure 10 — Spin-up test of payload and third stage assembly

Program for Interplanetary Probe P-14*", dated October 3, 1960. The engineering model and the prototype model were subjected to prototype environmental tests which were approximately 50 percent more severe than the anticipated flight conditions. The flight models were limited to flight level tests to avoid any possibility of approaching the fatigue point of main structural members.

The payloads were subjected to the tests summarized in Table 2. In order to test the ability of the sensor arms and antennas to snap down and lock in place when released during second stage acceleration, calibrated elastic bands were attached to the arms so that they pulled down in a manner which simulated acceleration forces.

FIELD OPERATIONS

Flight model two was chosen to be the test model for preliminary launch operations at the Atlantic Missile Range (AMR). The model arrived at Cape Canaveral, Florida, by air at T-12 days. The assembly area was set up and the payload checked out. Magnetic field tests were conducted and antenna pattern checks were made. The payload was then assembled to an inert third stage and alignment checks with the spin table axis were made (Figure 11). A misalignment of 0.104 inch total indicator reading (TIR) was allowable but the assembly proved to be out by only 0.020 inch TIR. A special alignment button was provided on the tip of the payload for these checks. The third stage rocket and payload assembly was then enclosed in a hoisting fixture and lifted to the top of the gantry. The fixture was removed and the assembly was mated to the second stage. The air conditioning system, including payload tent and third stage blanket, was then installed and tested. Since it was not desirable to blast cool air directly down onto the temperature sensitive bias sphere, a special tent lid was made which admitted air only around the periphery of the lid (Figure 12). Once the air conditioning system was found to work satisfactorily, the protective stripable coating was removed from the payload. The nose fairing was then assembled in place and all interface connections made. The antennas and sensor arm handling locks were removed through the access ports and the turn-on plug was installed. The gantry was moved back and complete AMR systems tests were performed. As shown in Figure 13, conditioned air was fed to the payload-third stage assembly via umbilical tower ducts until the instant of launch. The air inlet post on the fairing was at the base of the payload and did not adversely affect the sphere temperature. Upon successful completion of the preliminary countdowns, stripable coating was reapplied to the payload and the unit was returned to the protection of its shipping container.

While the test payload was undergoing gantry tests, the flight payload and its backup were undergoing final checks. A check-off list for mechanical items was initialed by assembly technicians to assure the proper condition of every screw, nut, and mechanical device. The flight payload was mated to the flight third stage on T-5 days and the

*The Explorer X satellite was known as P-14 before the launch.

TABLE 2

TESTS OF THE EXPLORER X PAYLOAD

TEST	LIMITS	APPLICABLE PAYLOAD
Dynamic Balance	Lead, as required	Prototype and Flight Models
Spin	140 rpm	Prototype
	110 rpm	Flight Models
Temperature	18° to 62°C	Prototype (sphere area)
	0° to 50°C	Prototype (electronics area)
Shock	Two 1/2 sine shock pulse of 22.5 g peak amplitude and 11 msec duration.	Prototype
	One 1/2 sine shock pulse of 15 g peak amplitude and 11 msec duration.	Flight Models
Vibration	Sinusoidal: 5 to 5000 cps; 1.5 to 60 g rms thrust axis, 0.6 to 20 g rms transverse axis; 0.5" peak to peak.	Prototype
	Random: 20 to 2000 cps at 11.5 g rms, both axes.	Prototype
	600 cps: 550 to 650 cps at 60 g rms thrust axis, 15 g rms transverse axis.	Prototype
	Sinusoidal: 5 to 5000 cps; 1 to 40 g rms thrust axis and 0.4 to 8 g transverse axis; 0.5" peak to peak.	Flight Models
	Random: 20 to 2000 cps; 7.7 g rms both axes.	Flight Models
	600 cps: 550 to 650 cps; 40 g rms thrust axis 8 g rms transverse axis.	Flight Models
Acceleration	18 g-arms folded; 33 g-arms extended.	Prototype
Thermal Vacuum	From 10°C above expected maximum to 10°C below expected minimum at 1×10^{-4} mm Hg.	Prototype
	From expected maximum temperature to expected minimum temperature at 1×10^{-4} mm Hg.	Flight Models

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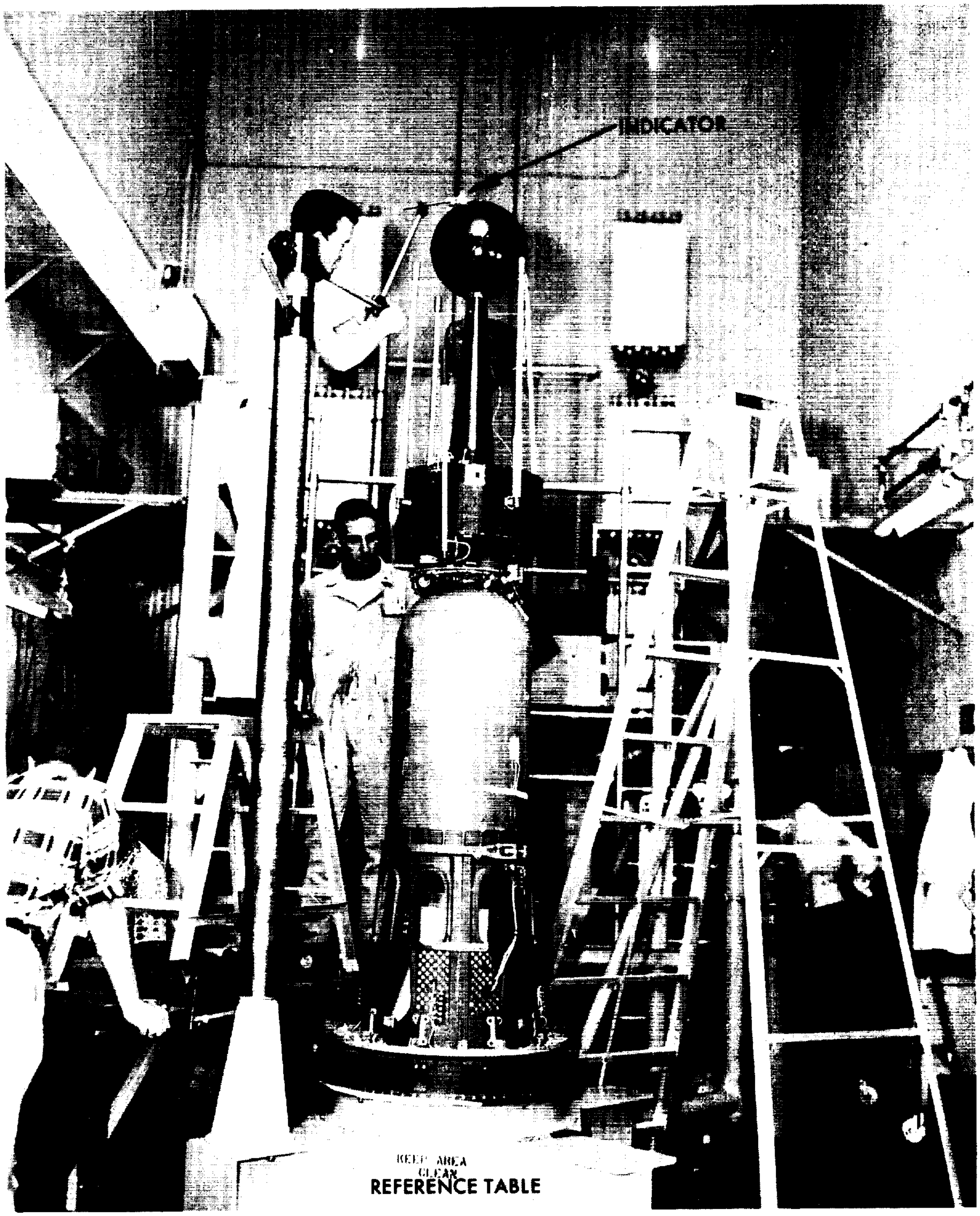

Figure 11 — Alignment checks at AMR

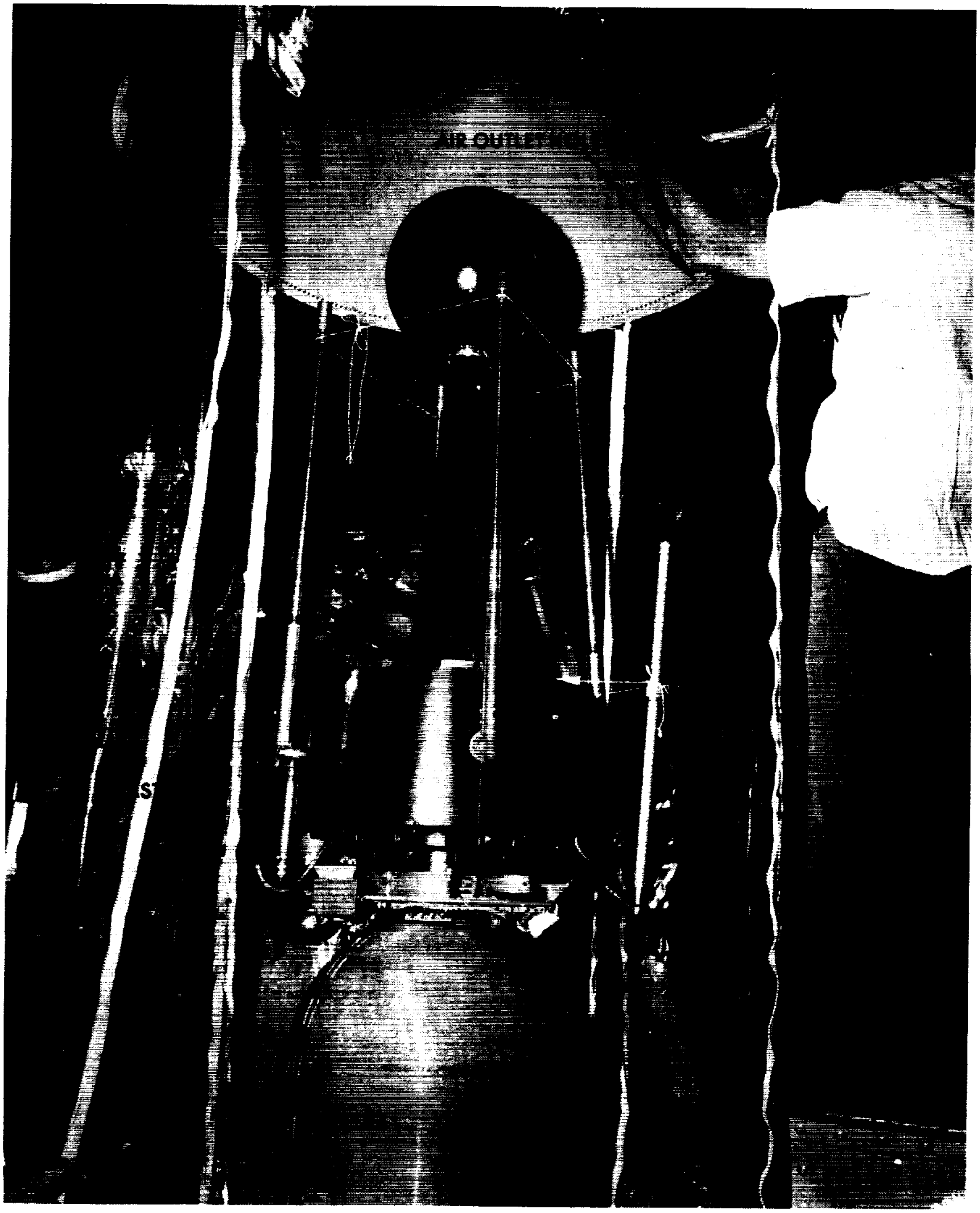

Figure 12 — Air conditioned tent on gantry

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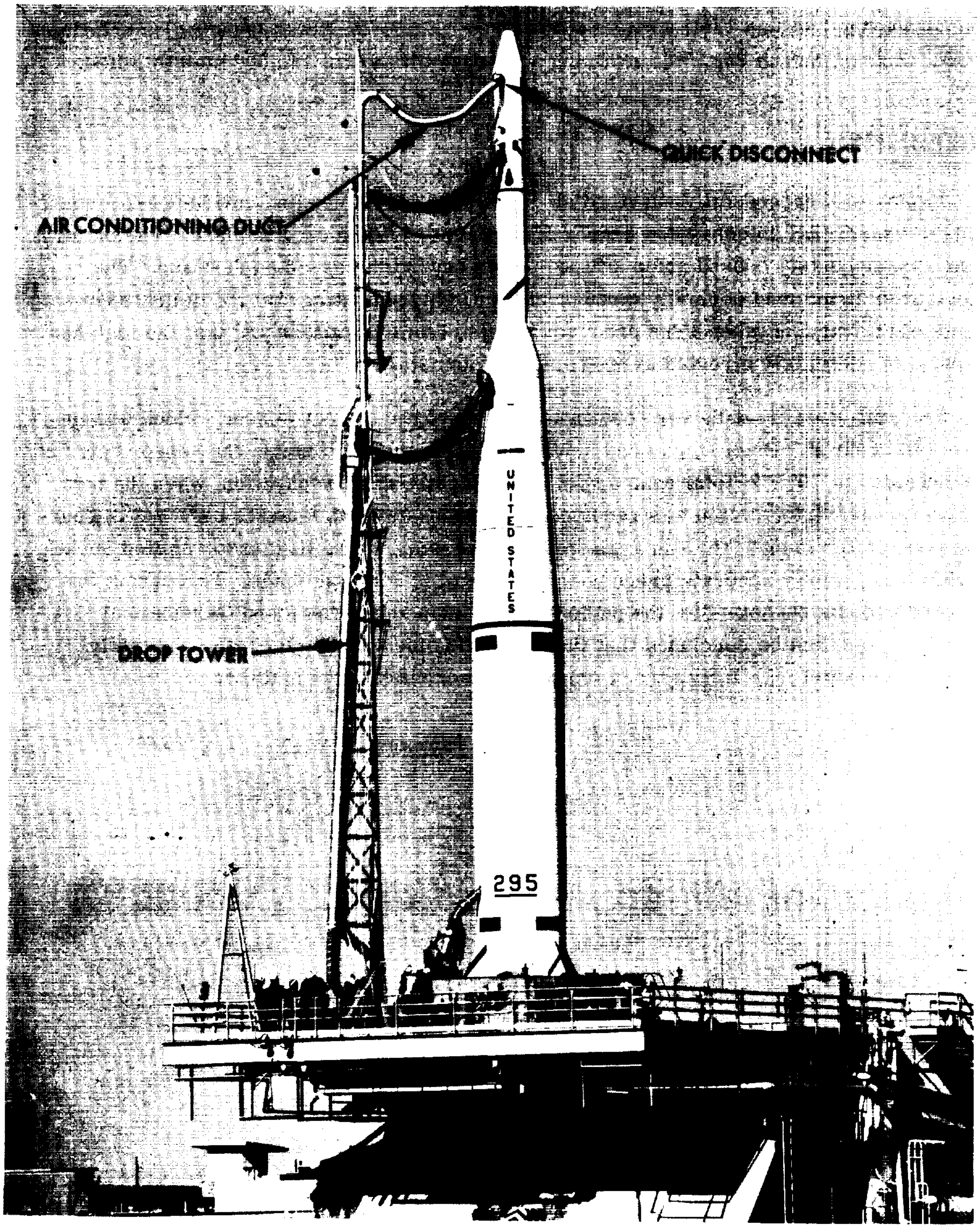

Figure 13 — Pre-launch air conditioning ducts

assembly was installed on the missile on T-4 days. Due to an exceptionally smooth countdown, the back-up payload was not required. Explorer X was launched as scheduled at 1017 EST on March 25, 1961, attaining an apogee altitude of 145,000 statute miles.

CONCLUSIONS

Explorer X successfully survived all launch vehicle forces and environmental conditions of space. All antennas and sensor arms unfolded and locked in place. The battery pack was adequately housed and produced power beyond the expected duration. The transmitter functioned normally throughout the flight, indicating that the delicate filaments of the vacuum tubes were properly isolated from vibrations and that the high heat output was adequately directed away from the transistors.

The spin stability data were obtained from the optic aspect sensor, which was accurate to about 2°. Prior to payload separation from the third stage, the sensor detected a precession of $10° \pm 2°$ total cone angle. Two minutes after separation, when the next pulse of sensor information was received, the precession was found to be $0° \pm 2°$. Fourteen hours after launch, the sun angle reached the point where the sensor shifted buckets. At this time, a very accurate precession reading of $0° \pm 1'$ was made. Throughout the remainder of its 60-hour life, the payload precession angle was found to remain at $0° \pm 2°$. It can thus be concluded that the payload moment of inertia ratio of slightly more than unity ($I_{spin}/I_{tumble} = 1.03$) provided excellent spin stability.

Appendix A

Explorer X Weight Summary

Table A1

Component and Battery Weights

Component Description	Weight (pounds)
Cable harness	.970
Antenna harness (with dummy load)	.254
Braided cable (magnetometer and sensors)	.172
Timing central module	.467
Encoder module	.585
Gates module (program encoder)	.345
Bias sphere module	.335
Fluxgate "A" (module and sensor)	.718
Fluxgate "B" (module and sensor)	.714
Magnetometer amplifier module	.519
Optic aspect module	.626
Aspect computer module	.398
Optic aspect sensor (potted)	.370
Plasma probe sensor	1.402
Plasma probe module	1.124
Rubidium lamp and gas cell assembly	1.023
Transmitter power amplifier	.793
Transmitter oscillator	.652
Batteries (168 cells and wiring)	34.000
Transmitter internal harness	.090
Magnetometer oscillator	.430
Miscellaneous wire	.044
Total Component and Battery Weight	46.031

Table A2

Structure and Mechanisms Weight

Structure and Mechanisms	Weight (pounds)
Tube cap	.039
Tube cap insert	.051
Bias sphere (therm. coated)	.946
Tube collar, upper	.039
Tube collar, lower	.051
Support tube (therm. coated)	1.620
Battery housing	4.178
Battery housing cover	1.887
Battery housing clamp	.220
Battery housing cover O-rings	.050
Upper shelf	1.598
Optic aspect holder	.112
Turn-on plug bracket	.071
Turn-on plug (potted)	.084
Disconnect plug bracket	.033
Plasma probe housing ring	.311
Plasma probe stand-off	.112
Plasma probe support	.064
Plasma probe housing strap	.032
Battery insulation, top layer	.374
Battery insulation, shelves	.683
Battery insulation, midlayer	.364
Battery insulation, bottom layer	.745
Girth band	.240
Battery housing plug (potted)	.148
Antenna support weldments (4 assemblies)	2.540
Battery jumper plug mount	.007
Antenna components (for 4 assemblies)	
Cap	.054
Cup	.599
Insert	.397
Stub	.497
Swivel pin	.004
Tube	2.126
Piston	.418
Socket	.410

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Table A2 (Continued)

Structure and Mechanisms	Weight (pounds)
Spring	.473
Guide pin	.001
Detent	.005
Detent spring	.001
Spin stabilizing weights (4)	4.000
Cable mount	.022
Transmitter can (with shock mount)	1.420
Module holddown bar	.079
Module holddown rod	.124
Bar cable mount	.020
Holddown nuts	.047
Ground planes (therm. coated set)	.580
Fluxgate sensor support components (for 2 assemblies)	
Sensor arm bracket	.409
Socket	.260
Piston	.150
Spring	.236
Detent	.002
Detent spring	.001
Guide pin	.001
Swivel pin	.001
Stub	.125
Tube	.421
Shield socket	.028
Mount (potted and coated)	.176
Spacer	.001
Calibration coil cover	.031
Cable nipple	.018
Lower shelf	1.797
Pressure fill valve	.012
Bias sphere choke box	.034
Magnetometer shield box	.004
Assembly screws	.397
Total Structure and Mechanisms Weight	31.980

Table A3

Total Flight Payload Weight

Weight Source	Weight (pounds)
Total component and battery weight	46.031
Total structure and mechanisms weight	31.980
Balance weight	.900
Total Flight Payload Weight	78.911